TA-55 Leak Path Factor Analysis

In Response To SER Commitments

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ABSTRACT

The objective of this work was to update specific leak path factor calculations presented in the Los Alamos National Laboratories (LANL) Technical Area 55 (TA-55) Final Safety Analysis Report (FSAR) in response to commitments made in the Safety Evaluation Report (SER) to revise those calculations.

This effort is pertinent to the Accident and Consequence Analysis topic area. The work was undertaken based on the following approach:

Initially, a MELCOR analysis was performed for a single volume model with process gas sources to the lab area accompanied by the release of plutonium and uranium. This was the Evaluation Basis Earthquake (EBE) accident scenario presented in the FSAR. The single volume analysis was designed to benchmark the FSAR analysis in order to serve as a suitability check on MELCOR itself.

Additional analyses were performed using a more complex, multi-volume MELCOR model in order to observe some of the subtle behavior characteristics that are apparent only when modeling inter-volume flows and transport of radionuclides. Movement of material from the laboratory to the environment was the primary interest. The analysis included the following:

- A single run similar to the EBE process gas addition accident scenario with the specification of multiple control volumes and separate locations where the process gases were sourced into the lab.

- Two calculations modeling different size fires, based on reasonable combustible loadings in a single lab room, to provide the energetic mechanism to move radionuclides through the lab rooms to the environment.

- Two calculations modeling different explosive events. The first explosion was based on a process scenario. The second explosive scenario was based on an explosion in a lab room resulting from leakage of combustible stored gas.

Results for the EBE accident scenario indicate that settling of released radionuclides results in a much smaller leak path factor than was predicted by the single volume analysis presented in the FSAR. For the fire and explosion accident scenarios, leakage of radionuclides to the external environment is mitigated when HEPA filters are functional, even for cases when the ventilation fans are not operating. Leak path values are increased when doorways to the external environment are modeled as partially open. For all cases, settling of aerosols within the laboratory room served to reduce the leak path to the environment.

These MELCOR simulations increase the level of understanding for three of the evaluation basis accident scenarios presented in the TA-55 FSAR. Through the use of a multi-volume model, the migration of radionuclides from a single room to other locations within the laboratory facility can be tracked with respect to location and timing. In addition to leak path factor values, these results provide more detailed information on contamination within the laboratory building than was available using a single volume model.

Introduction

A series of time dependent leak path factor calculations have been performed for the Los Alamos National Laboratories (LANL) Technical Area 55 (TA-55) Plutonium Facility, Building 4 (PF-4). These calculations were accomplished to support the commitments made in the Safety Evaluation Report (SER) to revise certain specific leak path factor calculations presented in the TA-55 Final Safety Analysis Report (FSAR) [1].

The following set of analyses were carried out using MELCOR [2], a severe accident analysis computer code originally designed to simulate accidents in nuclear power plants:

1. An analysis using a simple, single volume MELCOR model with a process gas source to the lab area and the release of plutonium and uranium to the laboratory. This is the Evaluation Basis Earthquake (EBE) accident scenario presented in the FSAR. The primary purpose of the MELCOR single volume analysis was to validate the results presented in the present FSAR by using the same modeling inputs and assumptions. This effort was designed to serve as a *sanity check* on the suitability of MELCOR as a tool to analyze PF-4 accident scenarios.

2. Performance of analyses using a more complicated, multi-volume MELCOR model in order to observe some of the more subtle behavior characteristics that are apparent only when inter-volume flows and transport of radionuclides are modeled. The accident scenarios analyzed included the following:

    i.   A suite of MELCOR runs analyzing accident scenarios identical to the EBE process gas addition accident scenario described above, only with the specification of multiple control volumes and separate locations where the process gases are sourced in to the lab. Additional EBE-type accidents were analyzed to gain insight into the effects of ventilation fans and HEPA filters on the observed leak path factor to the external environment.

    ii.   A suite of calculations using fires based on reasonable combustible loadings in a single lab room to provide the energetic mechanism for dispersal of radionuclides in the laboratory atmosphere.

    iii.   A suite of calculations using different explosive events as the energetic mechanism for dispersal of radionuclides in the laboratory atmosphere. The first explosion is based on a process scenario defined in the FSAR as a hydrogen deflagration associated with a plutonium hydride/dehydride process and occurs in a glovebox. The second scenario is based on hypothetical explosions in a lab room resulting from leakage of combustible stored gas.

MELCOR Code Description

The MELCOR code, developed at Sandia National Laboratories for the U. S. Nuclear Regulatory Commission, is a fully integrated computer code designed originally to model the progression of severe accidents in light water reactor nuclear power plants. Major elements of the code are applicable, in general, to many other problems involving fluid flow, heat transfer, thermodynamics, and transport of airborne contaminants in aerosol and vapor form. This capability makes the MELCOR code a useful tool

for evaluation of hazardous materials within DOE facilities. The MELCOR code was subjected to a peer review in 1992 [3] and has been subjected to model validation studies throughout its development.

The MELCOR code was adapted to simulate accidents at the PF-4 laboratory facility through user input (no code modifications were needed) by activating only the applicable code models, specifically the thermal-hydraulic models, heat sink models, and the radionuclide transport models. The core meltdown models, for example, remained dormant.

MELCOR models thermal-hydraulic behavior using a lumped parameter approach applied to control volumes interconnected by flow paths. The thermodynamics package calculates the thermodynamic state of the materials in each control volume from the total volume, energies, and masses calculated by the control volume hydrodynamics package. Each volume is defined spatially by its volume versus altitude. The contents of a control volume may be divided into a "pool" containing subcooled (liquid) or saturated (two-phase) water, and an "atmosphere" containing water vapor, liquid water "fog", and noncondensible gases.

Control volumes are connected by flow paths through which the hydrodynamic materials may move without residence time or heat transfer, driven by a separate momentum equation for each field. Each control volume may be connected to an arbitrary number of others, and parallel flow paths (connecting the same pair of volumes) are permitted. There are no restrictions on the connectivity of the network built up in this way. The flow paths may represent either a pipe-like connection in a tank-and-tube model or a cell boundary in a finite-difference model, allowing considerable modeling flexibility. Appropriate hydrostatic head terms are included in the momentum equations for the flow paths, allowing calculation of natural circulation.

Heat structures are used to model the transfer of heat between control volume atmospheres and pools and their surrounding surfaces. A heat structure is an intact, solid body that is represented by one-dimensional heat conduction with specified boundary conditions at each of its two boundary surfaces. In this study, heat structures were utilized to model floors and ventilation system ductwork. In order to be conservative, laboratory walls and internal equipment were not included as heat structures. Conductive, convective, and radiant heat transfer may occur at heat structure boundaries, depending on the modeling assumptions being used.

The MELCOR code contains models to predict the transport and behavior of radionuclide vapors and aerosols that directly couple to the thermal-hydraulic models. Radionuclides are grouped into elemental classes, where the constituents of each class show similar transport and deposition behavior. Radionuclides may exist in either a vapor or an aerosol form and may combine with other non-radioactive materials such as aerosols formed during the melting of structural materials. The aerosol dynamics models were adapted from the multicomponent MAEROS code [4]. The condensation and evaporation of vapors from heat structures and aerosols is evaluated by equations adapted from the TRAP-MELT code [5]. Radionuclide aerosols and vapors may deposit directly on surfaces such as heat structures and water pools and aerosols may agglomerate and settle. The particle coagulation processes that may be modeled include Brownian diffusion, gravitational settling, and turbulent impaction. The aerosol deposition processes available for modeling include gravity, diffusion, thermophoresis, and diffusiophoresis. Resuspension was not modeled for the PF-4 accident analyses. MELCOR has additional models for fans, sprays, HEPA filters, and vapor chemistry.

MELCOR Input Models

Three nodalizations of the PF-4 facility were used for the analyses. A single volume MELCOR model was created to perform a confirmatory analysis based on the EBE accident scenario presented in the TA-

55 FSAR. Subsequently, a multiple volume MELCOR model was used to carry out additional runs simulating various earthquake, fire, and explosive deflagration accidents, some of which were presented in the TA-55 FSAR.

The EBE simulations used a slightly less detailed nodalization than the Evaluation Basis Deflagration (EBD) accidents. For the Evaluation Basis Fire (EBF) and EBD accidents, the building was described using 24 control volumes representing actual rooms, corridors, and stairways; 2 control volumes representing ventilation system exhaust headers and ductwork; and two control volumes representing the ambient atmosphere external to the facility.

Control Volumes

The main laboratory floor was modeled in the greatest detail. The space comprising 300 Area was subdivided into three parts represented in the MELCOR input file as Lab-305, Lab-319, and Lab-327. The 400 Area was subdivided into control volumes with MELCOR representations of Lab-401, Lab-420, and Lab-429. A volume representing the corridor separating 300 Area and 400 Area was specified as Corridor-320. A similar process was followed for the control volumes associated with 100 Area, 200 Area, and the corridor separating the two areas. Stairwells in the 200 Area, 300 Area, and 400 Area were modeled as separate control volumes, while the volumes associated with the stairwell adjacent to the 100 Area lab rooms were included as part of those volumes. The mezzanine area was modeled as two separate control volumes, while the basement was specified as a single control volume. The basement vault was included in the single basement volume and was not modeled separately.

Flow Paths

For any MELCOR model, the interconnecting flow paths are the conduits that allow the control volumes to communicate with each other in a thermodynamic sense. Over seventy flow paths are used to interconnect the control volumes for the accident simulation runs. For the EBE accidents, flow paths are included that model leakage pathways from the basement to the environment due to severed penetrations not involved in the supply of process gases. Similar severed penetration pathways exist that pass through the laboratory level walls to the environment and through the mezzanine roof to the environment. Numerous flow paths are defined that model flow between adjacent laboratories, flow from corridors to laboratories and stairwells, and flow from one corridor to the other. Flow path losses were modeled by the specification of loss coefficients in the MELCOR input files. The loss coefficients were determined based on pressure drops, flow rates, and friction losses for each flow path. Pressure losses across HEPA filters were not modeled. Fresh makeup air is available via flow paths connecting the environment to the basement inlet. Bleed off flow paths exist to allow air to be exhausted from the basement and from the labs to the environment via exhaust plenums. For the mezzanine and each lab control volume, flow path connections exist that provide for fresh air supply and bleed off air exhaust, where applicable.

Heat Structures

Another feature present in the MELCOR model is the definition of heat structures for each of the control volumes. For the control volumes defined as actual rooms and corridors, the heat structures were specified as the concrete floors associated with those rooms. For the control volumes defined as ventilation plenums, heat sinks were specified as eighth inch thick stainless steel. All horizontal floor-type heat sinks are available for aerosol deposition.

Radionuclides Released to the Laboratory Atmosphere

Three radionuclide releases were modeled, one for each of the three different accident types investigated. Each of these releases is presented below.

For the EBE accident, the final material at risk (MAR) has been specified in the MELCOR input as 1-micron diameter plutonium and uranium aerosols. The MAR was dispersed among the various laboratory rooms as described in Appendix 3C of the TA-55 FSAR. Dispersal to the room atmospheres was accomplished during a one-second time period at the start of the accident.

For the EBF and Beyond Evaluation Basis Fire (BEBF) accidents, the final MAR was specified in the MELCOR input as a 1-micron diameter plutonium aerosol, in order to simulate a finely ground powder. The radionuclide release, 0.20 g of plutonium for the EBF accident and 0.40-g for the BEBF accident, was placed in Room 207. All released material was distributed to the Room 207 atmosphere during a one-second time period at the beginning of the accident.

For the EBD accident, the final MAR was specified in the MELCOR input files as a 1-micron diameter plutonium aerosol, in order to simulate a fine plutonium hydride. The source term, 6.75 g of plutonium for the explosive accidents, was placed in Room 114. All source term material was distributed to the Room 114 atmosphere during the first second of the accident simulation.

HEPA Filters

When mitigated accidents were analyzed, filters were placed in the fresh air inlet and exhaust air outlet flow paths. These filters simulated the single HEPA filter train in place on the fresh air makeup flow path and the double HEPA filtration trains in place on the bleed off exhaust flow paths. Single stage HEPA filter trains were modeled as 99.9% efficient. Two stage HEPA filter trains were modeled as 99.9% efficient for the first stage and 99.8% efficient for the second. HEPA filter pressure losses and clogging were not modeled.

Mass and Energy Additions to Laboratory Control Volume Atmospheres

For the earthquake accident scenarios, gases were sourced into the basement control volume to simulate the inflow of process gases through severed supply lines as a result of seismic activity. At atmospheric pressure the combined volume of process gases associated with PF-4 is approximately 2.1×10^6 ft^3 and is dominated by the 6,000-gal dewars of liquid argon and liquid nitrogen located outside PF-4. The combined flow rate from all gas cylinders, tube trailers, and the dewars diminishes over time as successive sources are exhausted. All gas cylinders and tube trailers are depressurized within 18 hours, but the liquid nitrogen dewar is calculated to take over 90 hours to deplete. The addition of the process gas inventories is modeled in the MELCOR input through the use of multiple tabular functions. Mass and energy addition rates are specified with appropriate time histories to allow for depletion of process gas sources at different times during the accident.

For the fire accidents, energy was added to the atmosphere in Room 207 to simulate a fire in that room. The average rate of energy generated by the fire is defined as 8.34×10^5 BTU/hr (244 kW) over the 2.1 hr duration of the fire. That is the rate of energy addition modeled in the MELCOR EBF and BEBF accident simulations.

For the explosive deflagration accidents, energy was added to the atmosphere in Room 114 to simulate different sizes of explosions in that room. The energy generated by the EBD explosive accident is defined as the deflagration of 6.1 moles of hydrogen, the equivalent of 36.7 g (1.3 oz) of TNT. The

energy was added to the Room 114 atmosphere over a period of 0.005 s at the outset of the accident. Additional MELCOR runs were executed with 0.5-LB and 1 LB charges of TNT providing the explosive energy to the Room 114 atmosphere. The energy associated with those charges was added over a 0.005 s time period at the outset of the accident, just as was done for the EBD hydrogen deflagration case.

ACCIDENT Scenario Descriptions

The specific conditions pertinent to each of the three accident types examined are described in the following paragraphs.

Earthquake Accidents

The EBE-type accident is defined as one in which seismic activity causes failure of process enclosures and the free fall spillage of the MAR into the laboratory rooms. Attendant to this action, process gas lines are predicted to rupture due to seismic accelerations resulting in discharge of the stored gas inventories into the laboratories. Then, suspended material is subject to release through various leak paths, driven by the discharge of process gases. The ventilation system is assumed to be inoperable due to loss of offsite power and failure of non safety-class ducting within the facility.

Fire Accidents

The EBF-type accident is described as a fire that occurs in Lab-207 adjacent to a glovebox, with the fire breaching the glovebox. The source term in the glovebox is finely divided heat-source plutonium in oxide form. A localized fire propagates from low level waste boxes filled with combustible room waste stacked in front of the glovebox and ignited due to internal heat generation or a spill of flammable liquid. The laboratory room is unattended, and the initiating fire is allowed to ignite the bottom of a PMMA slab used to shield workers against neutrons emitted from materials inside the glovebox. The fire suppression system is not available or does not put out the fire, and the PMMA burning surface grows upward and burns the gloves, breaching the glovebox. The ventilation system is unavailable. Aerosol and combustion product gases produced by the fire are convected throughout the room, into the ventilation ductwork, and into the neighboring rooms and corridor via door gaps. The resultant amount of radioactivity released into the environment depends on the transport of the aerosol within PF-4 and the openings present, external doors; building leakage; and ventilation inlet, exhaust, and bleed-off paths.

For the BEBF, the accident scenario is identical to the EBF accident except two gloveboxes are assumed to be involved, and two sets of exterior doors are assumed to remain open for the duration of the fire.

Explosive Deflagration Accidents

Three explosive deflagration accidents were modeled. The only difference between them is the size of the explosive event used as a mechanism to distribute MAR to the laboratory atmosphere. The first explosive event modeled is based on a process scenario and occurs in a glovebox. This EBD scenario is defined as a hydrogen deflagration in the hydride/dehydride glovebox. The second scenario modeled is based on a hypothetical explosion in a lab room resulting from leakage of combustible stored gas. This scenario is not documented in the TA-55 FSAR.

The first scenario examines the potential effects of a hydrogen deflagration within a glovebox. The quantities of hydrogen stored within PF-4 are insufficient to create a flammable mixture within the rooms where it is stored or used. The areas of potential concern are smaller, enclosed volumes where the hydrogen concentration could build up to a flammable or detonable mixture. The FSAR postulates the highest consequence hydrogen deflagration to occur in a hydride/dehydride glovebox in Lab-114.

The EBD explosive accident is modeled as a hydrogen deflagration in Room 114. It is assumed to occur due to multiple equipment failures and operator errors that lead to a buildup of hydrogen and an inflow of oxygen in the inert-atmosphere glovebox used in the hydride/dehydride process. An ignition source is

assumed to be present, and the hydrogen deflagrates. The vacuum chamber used for the hydride reaction is assumed to be opened due to the deflagration, and part of the plutonium hydride powder within the vacuum chamber is suspended as an aerosol. A portion of the suspended aerosol is released from the glovebox to the room, and the ventilation system is assumed inoperable. Part of the aerosol released to the room passes out of the facility through the inlet and exhaust pathways and the gaps around doors connecting the laboratory corridors to the external environment. The consequences of the hydrogen deflagration are assessed assuming that the laboratory structure remains intact. The EBD run is modeled with failed ventilation fans and operable HEPA filter trains.

The MELCOR runs associated with hypothetical explosions in a lab room resulting from leakage of combustible stored gas were modeled to occur in Room 114, too. Conditions were identical to the EBD accident with the exception that the sizes of the explosive events were different.

Accident Results

The results of the MELCOR runs for each of the accident scenario types are described in the following paragraphs.

Single Control Volume Earthquake Accidents

A series MELCOR runs were made using the single volume PF-4 model in an attempt to replicate the EBE analysis presented in the TA-55 FSAR. This accident scenario was used as a basis for a series of input variations in order to determine if MELCOR was capable of modeling the types of accidents anticipated as being important for PF-4. Parameters varied included free volume size, heat sink areas, aerosol deposition surfaces, sizes of flow paths to the external environment, and the properties associated with the uranium and plutonium aerosols released to the laboratory atmosphere during the EBE accident. The final single volume run used for comparison against the results presented in the TA-55 FSAR was designed as a release with an unmitigated flow path area between the laboratory and the external environment of 2.439 m^2. The EBE leak path factor presented in the FSAR for this accident was 0.59 after 96 hrs, while the MELCOR analysis predicted a leak path factor of 0.48 for the same accident duration.

Multiple Control Volume Earthquake Accidents

A series of multiple volume MELCOR runs were made for the EBE accident defined in the TA-55 FSAR and variations from that base case. All of the runs use certain common inputs, such as those specifying aerosol source terms and others specifying process gas sources to the basement control volume. These inputs will be described briefly now.

TA-55 FSAR Appendix 3C, *Evaluation Basis Earthquake Source Term Analysis*, was used as the reference document that describes how the plutonium and uranium MAR is distributed throughout the PF-4 labs. The four runs described have the MAR distributed throughout the facility via a mapping of inventories listed in Appendix 3C to the corresponding control volume defined in the MELCOR input files. For cases where a laboratory room contained both plutonium and uranium, the entire MAR in that particular room was defined as plutonium.

Process gases were sourced into the basement via the use of MELCOR tabular functions. The salient points that set the various runs apart from each other can be summarized in a sentence or two. Besides the location of the MAR, the remaining differences have to do with whether any inlet and exhaust flow paths are filtered, whether unfiltered penetrations into the basement and labs due to severed penetrations are present, and whether a corridor door is ajar.

Table 1 contains descriptions of the characteristics of the EBE-type runs and their time dependent leak path factors. The first two of these runs were designed to correspond to the EBE runs reported in the TA-55 FSAR. One is an unmitigated run (no credit taken for HEPA filters) and the other is mitigated (credit taken for HEPA filters). The remaining two runs are identical to those just mentioned except an exterior door is ajar.

Table 1: MELCOR EBE Run Leak Path Factors

(Page 1 of 2)

Run ID	Run Description	Leak Path Factors							
		1 Hr	2 Hr	12 Hr	24 Hr	36 Hr	48 Hr	72 Hr	96 Hr
EBE, Mitigated	Evaluation Basis Earthquake run with MAR distributed throughout laboratory as defined in TA-55 FSAR, Appendix 3C. Leakage pathways include severed penetrations in basement and laboratory walls, fresh air inlet, and exhaust air outlet. HEPA filters operable.	Plutonium							
		5.5E-4	1.1E-3	4.8E-3	7.1E-3	9.5E-3	1.1E-2	1.4E-2	1.5E-2
		Uranium							
		4.6E-5	9.7E-5	4.3E-4	6.9E-4	1.1E-3	1.4E-3	2.1E-3	2.6E-3
EBE, Unmitigated	Evaluation Basis Earthquake run with MAR distributed throughout laboratory as defined in TA-55 FSAR, Appendix 3C. Leakage pathways include severed penetrations in basement and laboratory walls, fresh air inlet, and exhaust air outlet. HEPA filters inoperable.	Plutonium							
		5.8E-4	1.3E-3	6.8E-3	1.3E-2	1.7E-2	2.2E-2	2.8E-2	3.0E-2
		Uranium							
		8.2E-5	2.3E-4	2.5E-3	5.6E-3	1.2E-2	1.8E-2	2.7E-2	3.2E-2

Table 1: MELCOR EBE Run Leak Path Factors

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Run ID	Run Description	Leak Path Factors							
		1 Hr	2 Hr	12 Hr	24 Hr	36 Hr	48 Hr	72 Hr	96 Hr
EBE, NW Door Ajar, Mitigated	Evaluation Basis Earthquake run with MAR distributed throughout laboratory as defined in TA-55 FSAR, Appendix 3C. Leakage pathways include severed penetrations in basement and laboratory walls, fresh air inlet, and exhaust air outlet. An exterior door is ajar. HEPA filters operable.	**Plutonium**							
		4.5E-4	9.7E-4	5.1E-3	8.2E-3	1.1E-2	1.3E-2	1.6E-2	1.7E-2
		Uranium							
		3.7E-5	7.7E-5	3.0E-4	5.1E-4	9.2E-4	1.5E-3	2.9E-3	3.7E-3
EBE, NW Door Ajar, Unmitigated	Evaluation Basis Earthquake run with MAR distributed throughout laboratory as defined in TA-55 FSAR, Appendix 3C. Leakage pathways include severed penetrations in basement and laboratory walls, fresh air inlet, and exhaust air outlet. An exterior door is ajar. HEPA filters inoperable.	**Plutonium**							
		4.9E-4	1.1E-3	7.1E-3	1.3E-2	1.7E-2	2.1E-2	2.6E-2	2.9E-2
		Uranium							
		7.4E-5	2.1E-4	3.4E-3	5.7E-3	9.4E-3	1.4E-2	2.3E-2	2.7E-2

Fire Accidents

The results from six MELCOR runs are reported in this section. The EBF and BEBF accident analyses presented in the TA-55 FSAR took credit for functional HEPA filter trains but assumed the ventilation system fans were inoperable. Two of the six MELCOR runs exhibit that combination of HEPA filter/ventilation fan operability. The remaining four runs have some combination of inoperable HEPA filters and functional ventilation fans. They serve as comparisons to the actual EBF and BEBF accident scenarios.

Leakage pathways to the environment for the fire accidents included basement and corridor fresh-air-supply intakes, laboratory bleed-off exhaust, and building leakage through gaps around external door openings. For the BEBF accident type scenarios, some exterior doors are modeled to be open while the remainder are closed.

Table 2 presents the leak path factors for each of the six runs for selected times extending for a duration of 96 hr. The salient points that set the various runs apart from each other are summarized in the Run ID and Run Description columns of the table.

Table 2: MELCOR EBF Run Leak Path Factors

(Page 1 of 2)

Run ID	Run Description	Leak Path Factors							
		1 Hr	2 Hr	12 Hr	24 Hr	36 Hr	48 Hr	72 Hr	96 Hr
EBF, Mitigated, No Fans (2.1 hr Fire, 244 kW average energy addition rate)	Evaluation Basis Fire run with source term located in Laboratory 207, as defined in TA-55 FSAR, Sec 3.4.2.1. Leakage pathways to the environment include leakage around closed corridor doors, through fresh air inlets, and exhaust air outlets. HEPA filters operable. Fans inoperable.	**Plutonium LPF**							
		6.0E-5	8.6E-5	1.2E-4	1.3E-4	1.4E-4	1.4E-4	1.4E-4	1.4E-4
Modified EBF, Unmitigated, No Fans (2.1 hr Fire, 244 kW average energy addition rate)	Modified Evaluation Basis Fire run with source term located in Laboratory 207, as defined in TA-55 FSAR, Sec 3.4.2.1. Leakage pathways to the environment include leakage around closed corridor doors, through fresh air inlets, and exhaust air outlets. HEPA filters inoperable. Fans inoperable.	**Plutonium LPF**							
		9.1E-2	0.145	0.265	0.318	0.341	0.350	0.356	0.357
Modified EBF, Mitigated, With Fans (2.1 hr Fire, 244 kW average energy addition rate)	Modified Evaluation Basis Fire run with source term located in Laboratory 207, as defined in TA-55 FSAR, Sec 3.4.2.1. Leakage pathways to the environment include leakage around closed corridor doors, through fresh air inlets, and exhaust air outlets. HEPA filters and fans operable.	**Plutonium LPF**							
		8.9E-7	1.6E-6	4.0E-6	4.0E-6	4.0E-6	4.0E-6	4.0E-6	4.0E-6

Table 2: MELCOR EBF Run Leak Path Factors

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Run ID	Run Description	Leak Path Factors							
		1 Hr	2 Hr	12 Hr	24 Hr	36 Hr	48 Hr	72 Hr	96 Hr
Modified EBF, Unmitigated, With Fans (2.1 hr Fire, 244 kW average energy addition rate)	Modified Evaluation Basis Fire run with source term located in Laboratory 207, as defined in TA-55 FSAR, Sec 3.4.2.1. Leakage pathways to the environment include leakage around closed corridor doors, through fresh air inlets, and exhaust air outlets. HEPA filters inoperable. Fans operable.	**Plutonium LPF**							
		0.293	0.432	0.658	0.661	0.661	0.661	0.661	0.661
BEBF, Mitigated, No Fans NW Door Open, (2.1 hr Fire, 244 kW average energy addition rate)	Beyond Evaluation Basis Fire run with source term located in Laboratory 207, as defined in TA-55 FSAR, Sec 3.4.2.1. Leakage pathways to the environment include leakage around some closed corridor doors with a fully open corridor door, through fresh air inlets, and exhaust air outlets. HEPA filters operable. Fans inoperable.	**Plutonium LPF**							
		1.4E-4	1.5E-4	1.8E-4	2.0E-4	2.1E-4	2.1E-4	2.2E-4	2.2E-4
Modified BEBF, Mitigated, With Fans NW Door Open, (2.1 hr Fire, 244 kW average energy addition rate)	Modified Beyond Evaluation Basis Fire run with source term located in Laboratory 207, as defined in TA-55 FSAR, Sec 3.4.2.1. Leakage pathways to the environment include leakage around some closed corridor doors with a fully open corridor door, through fresh air inlets, and exhaust air outlets. HEPA filters and fans operable.	**Plutonium LPF**							
		8.9E-5	1.1E-4	1.8E-4	1.8E-4	1.8E-4	1.8E-4	1.8E-4	1.8E-4

Explosive Accidents

The results from eight MELCOR runs are reported in this section. The EBD hydrogen deflagration accident analysis presented in the TA-55 FSAR took credit for functional HEPA filter trains but assumed the ventilation system fans were inoperable. An additional hydrogen deflagration accident was modeled with both the ventilation system fans and the HEPA filter trains operating normally. For further comparison purposes, the two hydrogen deflagration accident scenarios just mentioned were rerun with inoperable HEPA filters.

The remaining four MELCOR runs are 0.5 LB and 1 LB TNT explosive charge examples used to simulate hypothetical explosions resulting from leakage of combustible stored gas in Room 114. Two of the runs have operable HEPA filter trains and inoperable ventilation system fans. The remaining two runs have both the HEPA filter trains and the ventilation system fans operating.

Leakage pathways to the environment for the explosive accidents included basement and corridor fresh-air-supply intakes, laboratory bleed-off exhaust, and building leakage through gaps around external door openings. For all of the explosive accident runs, doors connecting the corridors to the environment are modeled as fully closed.

Table 3 presents the leak path factors for each of the eight runs for selected times extending for a duration of 96 hr. The characteristics that set the various runs apart from each other are summarized in the Run ID and Run Description columns of the table.

Table 3: MELCOR Explosive Accident Run Leak Path Factors

(Page 1 of 3)

Run ID	Run Description	Leak Path Factors							
		1 Hr	2 Hr	12 Hr	24 Hr	36 Hr	48 Hr	72 Hr	96 Hr
EBD Hydrogen Deflagration, Mitigated, No Fans (6.1 moles of H_2)	Evaluation Basis Hydrogen Deflagration run with MAR located in Laboratory 114, as defined in TA-55 FSAR, Sec 3.4.2.8. Leakage pathways to the environment include leakage around closed corridor doors, through fresh air inlets, and exhaust air outlets. HEPA filters operable. Fans inoperable.	Plutonium LPF							
		9.2E-7	1.3E-6	3.4E-6	8.0E-6	1.3E-5	1.7E-5	2.0E-5	2.1E-5
Modified EBD Hydrogen Deflagration, Unmitigated, No Fans (6.1 moles of H_2)	Modified Evaluation Basis Hydrogen Deflagration run with MAR located in Laboratory 114, as defined in TA-55 FSAR, Sec 3.4.2.8. Leakage pathways to the environment include leakage around closed corridor doors, through fresh air inlets, and exhaust air outlets. HEPA filters and fans inoperable.	Plutonium LPF							
		1.1E-2	3.2E-2	0.187	0.267	0.301	0.315	0.324	0.325
Modified EBD Hydrogen Deflagration, Mitigated, With Fans (6.1 moles of H_2)	Modified Evaluation Basis Hydrogen Deflagration run with MAR located in Laboratory 114, as defined in TA-55 FSAR, Sec 3.4.2.8. Leakage pathways to the environment include leakage around closed corridor doors, through fresh air inlets, and exhaust air outlets. HEPA filters and fans operable.	Plutonium LPF							
		1.1E-6	2.4E-6	1.4E-5	1.4E-5	1.4E-5	1.4E-5	1.4E-5	1.4E-5

Table 3: MELCOR Explosive Accident Run Leak Path Factors

Run ID	Run Description	Leak Path Factors							
		1 Hr	2 Hr	12 Hr	24 Hr	36 Hr	48 Hr	72 Hr	96 Hr
Modified EBD Hydrogen Deflagration, Unmitigated, With Fans (6.1 moles of H₂)	Modified Evaluation Basis Hydrogen Deflagration run with MAR located in Laboratory 114, as defined in TA-55 FSAR, Sec 3.4.2.8. Leakage pathways to the environment include leakage around closed corridor doors, through fresh air inlets, and exhaust air outlets. HEPA filters inoperable. Fans operable.	Plutonium LPF							
		0.311	0.516	0.867	0.871	0.871	0.872	0.872	0.872
Hypothetical Explosion #1, Mitigated, No Fans (0.5 LB, TNT)	Hypothetical explosion run (0.5 LB TNT equivalent) with MAR located in Laboratory 114, as defined in TA-55 FSAR, Sec 3.4.2.8. Leakage pathways to the environment include leakage around closed corridor doors, through fresh air inlets, and exhaust air outlets. HEPA filters operable. Fans inoperable.	Plutonium LPF							
		1.4E-6	1.8E-6	4.1E-6	8.8E-6	1.4E-5	1.7E-5	2.1E-5	2.1E-5
Hypothetical Explosion #1, Mitigated, With Fans (0.5 LB, TNT)	Hypothetical explosion run (0.5 LB TNT equivalent) with MAR located in Laboratory 114, as defined in TA-55 FSAR, Sec 3.4.2.8. Leakage pathways to the environment include leakage around closed corridor doors, through fresh air inlets, and exhaust air outlets. HEPA filters and fans operable.	Plutonium LPF							
		1.9E-6	3.6E-6	1.8E-5	1.9E-5	1.9E-5	1.9E-5	1.9E-5	1.9E-5

Table 3: MELCOR Explosive Accident Run Leak Path Factors

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Run ID	Run Description	Leak Path Factors							
		1 Hr	2 Hr	12 Hr	24 Hr	36 Hr	48 Hr	72 Hr	96 Hr
Hypothetical Explosion #2, Mitigated, No Fans (1.0 LB, TNT)	Hypothetical explosion run (1.0 LB TNT equivalent) with MAR located in Laboratory 114, as defined in TA-55 FSAR, Sec 3.4.2.8. Leakage pathways to the environment include leakage around closed corridor doors, through fresh air inlets, and exhaust air outlets. HEPA filters operable. Fans inoperable.	Plutonium LPF							
		2.6E-6	3.2E-6	6.0E-6	1.1E-5	1.6E-5	2.0E-5	2.3E-5	2.4E-5
Hypothetical Explosion #2, Mitigated, With Fans (1.0 LB, TNT)	Hypothetical explosion run (1.0 LB TNT equivalent) with MAR located in Laboratory 114, as defined in TA-55 FSAR, Sec 3.4.2.8. Leakage pathways to the environment include leakage around closed corridor doors, through fresh air inlets, and exhaust air outlets. HEPA filters and fans operable.	Plutonium LPF							
		3.0E-6	5.1E-6	2.4E-5	2.5E-5	2.5E-5	2.5E-5	2.5E-5	2.5E-5

Conclusions

The MELCOR runs for each of the accident scenario types provide a large amount of information concerning the movement of radionuclides through the PF-4 facility and out to the external environment. Conclusions gained from examination of the MELCOR results are given in the following paragraphs.

Earthquake Accidents

The leak path factors predicted by MELCOR are significantly smaller than those given in the TA-55 FSAR for the unmitigated EBE accident, dropping from 0.59 to approximately 0.03 after 96 hrs. Several factors contribute to this reduced value. The compartmentalization of the PF-4 MELCOR model into laboratories, corridors, basement, and mezzanine volumes allows more subtle transport phenomena to have an effect on the leak path to the environment. For instance, even though large amounts of process gases are released into the facility, the bulk of them enter through severed penetrations passing through the basement walls. Since there are additional severed penetrations modeled that penetrate the basement walls but are not involved with the leakage of process gases into the facility, there is a convenient pathway for a portion of the process gases to pass back out of the PF-4 basement to the external environment. These leakage pathways, along with additional fresh air inlet and exhaust air outlet passageways modeled for the facility, serve to reduce the magnitude of the pressurization of the PF-4 facility to a more benign level.

The plutonium and uranium MAR is distributed throughout the laboratory rooms as described in TA-55 FSAR Appendix 3C, *Evaluation Basis Earthquake Source Term Analysis*. Pressurization of the individual laboratories will vary according to the friction factors associated with the flow paths leading to each laboratory modeled. This factor, accompanied with the relatively modest pressurization of the laboratory facility due to the addition of the process gases results in more time for the suspended radionuclides to settle from the atmosphere before they can be exhausted to the external environment. This thesis is supported by tables of MELCOR results showing that the over 95% of the MAR for both radionuclides modeled remains in the PF-4 facility, mostly deposited on the floors of the various laboratory rooms modeled.

Thus, the MELCOR analysis for the EBE-type accidents is dominated by the settling of MAR to the floor of the various laboratory rooms. Release to the external environment is reduced to leak path factors values on the order of 3% or less.

Fire Accidents

The six fire accident MELCOR simulations all utilized the same size fire as the driving force for movement of the plutonium MAR throughout the laboratory rooms, a 2.1 hr fire with a 244 kW average energy addition rate as described in the TA-55 FSAR. Additionally, the MAR was modeled as 1-micron aerosol particles for each fire accident scenario. Since these factors remain constant, conclusions can be reached concerning the effects of ventilation fans and HEPA filters on the observed leak path factors. There are no real surprises in the conclusions reached based on the observed leak path factors. For the EBF accident, the leak path factor predicted by MELCOR, 1.4×10^{-4} at 96 hrs, was smaller than the FSAR value given as less than 1.1×10^{-2}. The additional MELCOR runs show clearly that functional HEPA filter trains are extremely important in reducing the leak path factors to the external environment. Operable ventilation fans were observed to decrease the leak path factor when accompanied by functional HEPA filters for the specific accidents simulated with MELCOR. That is true for accidents in general where the unfiltered leakage pathways make up a small portion of the total leakage pathway areas.

Explosive Accidents

The general conclusions applicable to the fire accident scenarios are equally applicable to the suite of explosive accidents modeled with MELCOR. Once again, functional HEPA filter systems are the major players in reducing the leak path factor to the external environment. Operable ventilation system fans increase the observed leak path factor when HEPA filters are bypassed. For the cases where HEPA filtration trains and ventilation system fans are functional in tandem, leak path factors were reduced for the cases simulated with MELCOR because radionuclides are transported to the HEPA filters by the fans at a faster rate.

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